Physics Basis of the AMS/IB Instrument

William W. Johnson
Los Alamos National Laboratory

The objective of this paper is to amplify the material presented at the FMTTD to establish the physics behind the AMS/IB. It is assumed that the reader is broadly familiar with the topic and with the viewgraphs, etc., that were presented during the demonstration, and the material presented here will not attempt to duplicate the viewgraphs. The characteristics of the Presence of Pu, Threshold Mass, and Isotopics measurements have been discussed on several previous occasions at meetings of technical experts of the United States and Russian Federation. Furthermore, the physics basis for the Symmetry measurement as performed at the FMTTD was originally suggested by Russian technical experts, and was adopted more or less intact for the demonstration, subject only to the caveat that the limitations of the detector allowed the symmetry measurements to be performed only about one axis, rather than two as originally suggested by Russian scientists. Accordingly the following discussion stresses the attributes of Age and Absence of Oxide.

Age. As in other initiatives, the attribute of "age" refers to time elapsed since *purification* of the plutonium, rather than *creation* of the plutonium. Radiation measurements to determine time elapsed since creation of the plutonium require prior knowledge (or agreed values) of the ^{241}Pu fraction in the plutonium at the time of its creation, information that is currently not under discussion for possible exchange owing to its sensitivity. The attribute therefore concentrates on the weaker condition involving purification, as time elapsed since purification can be determined via a simple radiation measurement without a-priori knowledge of the detailed isotopic composition of the material.

As demonstrated in the FMTTD and documented in the viewgraphs, the age measurement is based upon deducing the relative abundances of the isotopes ^{237}U and ^{241}Am, both daughters of the ^{241}Pu created along with the other plutonium isotopes in a production reactor. The ratio of abundance of ^{241}Pu to that of ^{237}U increases with the age of the plutonium. The decay of both isotopes leads to production of gamma radiation with energies near 332 keV and 335 keV, and the ratio of the intensities of the two lines is related to figure 1 as shown in Figure 1.

.

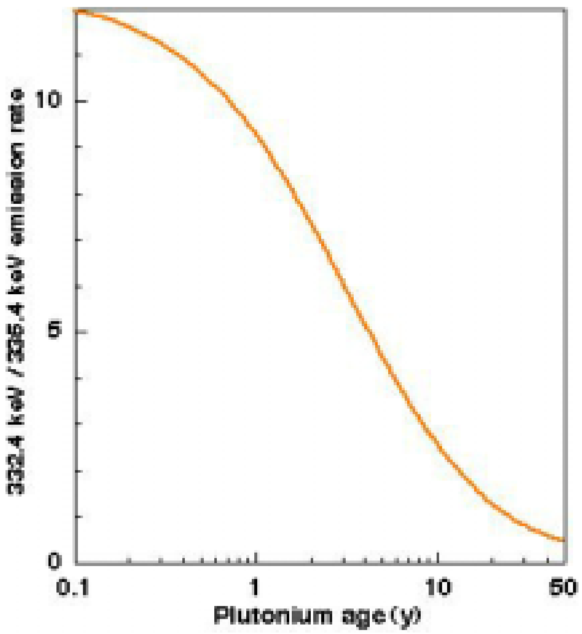

Fig. 1. Relation of plutonium age to the emission rates of the 332.4-keV and 335.4-keV γ rays produced in ^{237}U and ^{241}Am decay. The ratio is uncorrected for differential attenuation and for counts in a realistic γ-ray spectrum resulting from ^{239}Pu, which also emits γ radiation at energies near those of the lines of interest. (Figure courtesy T. B. Gosnell.)

The details of the age-determination method as used in FMTTD are covered in the viewgraphs and in the presentations dealing with the PU300 software. In practice age determination proved the least robust of the attribute measurements done in FMTTD; the reasons are also described in another presentation covering operational experience. Part of the problem lay in the difficulty in quantifying the contribution from ^{239}Pu (which, coincidentally and unfortunately, emits γ rays at energies close to those of the key lines) to spectra. Experience has shown that this quantification problem can be solved in a satisfactory way by using a wider region of the spectrum than was used in the demonstration. It should be recognized, however, that it was never an objective to present the *optimum* physics solution to measurement problems in this demonstration, but rather to show that attributes measurements could be done while protecting sensitive information. With the FMTTD successfully completed, it should now be possible to refine the algorithm, drawing upon the demonstrated ability to conceal sensitive information, when a need arises.

Absence of oxide. The physics basis of this attribute measurement resides in the interaction of α particles, produced in the decay of the main plutonium isotopes, with light elements that may be present. If the plutonium is intimately mixed with elements with atomic number less than about 15, the α particles may have sufficient energy to initiate nuclear reactions leading to emission of characteristic radiation, either neutrons or γ rays. (Reactions between plutonium α particles and nuclei of heavier elements are reduced owing to the latter's higher Coulomb barrier.) Appropriate detection algorithms might then be devised to determine whether admixture with various light elements has occurred. For the present demonstration, only admixture with oxide is considered, resulting from previous exchanges between US and Russian technical experts on possible attributes of plutonium of weapons origin. While the two sides were unable to reach agreement during those exchanges as to the suitability of oxide (more accurately, absence of oxide) as an attribute, it appeared prudent to demonstrate the capability for concealing sensitive information in a measurement associated with this attribute – this concealment, as always, being the primary goal of the FMTTD.

Details of the measurement approach are discussed in other presentations and written materials and generally will not be duplicated here. However, it appears useful to summarize recent results related to the 871-keV γ ray presumed to result from de-excitation of the first excited state of ^{17}O. There now appear to be both experimental and theoretical grounds to believe that most of the intensity of this line in the γ-ray spectrum results from the $^{14}N(\alpha,p\gamma)$ reaction on nitrogen entrained in the oxide, rather than the $^{17}O(\alpha,\alpha')$ reaction on the oxygen itself. This observation does not necessarily disqualify this line as an indicator relating to presence/absence of oxide, as the line is empirically observed to be present in most oxide samples and absent in normal metal samples (where there presumably is little opportunity for α particles produced in the bulk volume of the metal to come in contact with nitrogen in the air, the range of a 5-MeV α particle in plutonium metal being very short). In any event, the viability of the other part of the absence-of-oxide FMTTD measurement, namely the test for excess singles neutrons using the multiplicity counter, is not impacted by this finding.